Western Snow Conference, April 17-20, 2006, Las Cruces, New Mexico

Satellite Observations of the Date of Snowmelt at 70º North Latitude

J. L. Foster[1], D. A. Robinson[2], D. K. Hall[1], and Tom Estilow[2]

ABSTRACT

In this paper, we show changes in the dates of snow disappearance in the Arctic between the late 1960s and the early 2000s, from arbitrary but consistent boundaries, using National Oceanic Atmospheric and Administration (NOAA) satellite observations. The date the snowline retreats during the spring (when it first moves north of the 70º parallels), for many Arctic locations, has occurred approximately a week earlier in recent decades compared to the late 1960s. During this same period, substantial portions of the Arctic have been experiencing higher temperatures and a conspicuous diminution of sea ice, especially in the past 10 years. Our results generally agree with these observations -- the tendency toward earlier snowmelt previously observed was sustained until about 1990. Since this time, however, the date of snow disappearance has not been occurring noticeably earlier, and snow cover has actually been forming earlier in the autumn.

INTRODUCTION AND BACKGROUND

Climate models indicate that the Arctic is expected to provide the earliest indication of an incontrovertible global warming signal. Feedback effects associated with the high albedo of snow and ice result in the amplification of climate signals (Budyko 1966; Manabe et al., 1992). Both empirical and modeling studies have illustrated the influential role snow cover plays within the global heat budget (Walsh and Chapman, 1990; Robinson and Dewey, 1990). In the last two decades, various components of the cryosphere: snow cover, permanent ice over land, sea ice, and permafrost have been analyzed in an effort to measure changes in these features and to correlate any observed changes with available temperature records.

Foster et al. (1989) looked at the date of snow disappearance as measured at meteorological stations in the northern tundra of both Eurasia and North America. Results showed that for much of the North American tundra, the date of snow disappearance had been occurring earlier in the spring since the late 1960s, and in Barrow, Alaska, there had been a trend toward earlier snowmelt since about 1950. However, running means of the date of snow disappearance across much of northern Russia (north of 70 degrees north latitude) showed no discernible trend toward earlier melting.

In a 1992 study by Foster et al., it was confirmed, by utilizing only satellite observations, that the date of snow disappearance in the spring, north of 70 degrees north latitude, was indeed occurring earlier as compared to the 1970s and 1980s. In essence, the meteorological measurements in the 1989 paper were validated by the satellite data in the 1992 study.

[1] NASA/ Goddard Space Flight Ctr., Lab. for Hydrospheric and Biospheric Processes
[2]Rutgers University/ Department of Geography
Paper presented Western Snow Conference 2006.
By employing 12-month running means, Robinson et al. (1995) were among the first to detect a trend toward lower snow cover values in both Eurasia and North America and to recognize decreasing snow cover and to discuss the natural variability of snow cover. Robinson and Frei (2000) reported that an abrupt transition in snow cover extent occurred in the mid 1980s, during which time the average Northern Hemisphere snow extent decreased by almost 2 million km^2. The snow cover extent appeared to be inversely related to hemispheric surface air temperatures, and especially during the spring snow cover seemed to be strongly influencing temperature through various feedback mechanisms -- decreases in snow extent were particularly large in spring and summer.

Arctic warming has been noted in several recent publications concerning the diminution of sea ice. Also, a declining perennial ice cover has been observed by Comiso et al.(2002) among others. According to Comiso (2003), satellite thermal infrared data in the Arctic from 1981-2001 reveal large warming anomalies in the1990s compared to the 1980s. Furthermore, 2-year trends were 8 times larger than the 100-year trend, which suggest rapid warming conditions.

Moreover, Comiso and Parkinson (2004) noted that the Arctic has warmed by about 1º C in the past two decades. In fact, in the summer of 2002, the sea ice cover in the central Arctic was the smallest observed during the satellite era. However, sea ice cover was actually smaller in 2005. In September of 2005, sea ice extent in the Arctic was measured at 5.31×10^6 km^2 – the lowest ever measured during the satellite era (since 1978) and smallest size in at least a century (Comiso, personal communication). Over the 27-year satellite record (from 1978-2005), there has been an estimated 8.5% decline in Northern Hemisphere sea ice extent per decade (Comiso, personal communication).

Despite the large body of evidence cited above and elsewhere supporting warming in the Arctic, not every study has concluded that the Arctic is currently undergoing warming. For example, Przybylak (2000) found that the warming observed during and after 1975 becomes increasingly evident as one moves away from the Arctic, which seems to be the opposite of the prevailing paradigms. His work, which utilizes 37 stations in the Arctic and seven more in the sub-Arctic, suggests that at very high latitudes, current mean temperatures are near the minimum for the available period of record and that 5-year running means show a slight cooling trend since the 1980s.

Nor does every study point toward decreasing snow cover extent or duration. Bartlett et al (2005) reports that between 1950 and 2002 there was no significant trend in the mean onset date or snow cover duration for North America. Also, Frei and Gong (2005) show a rebound in snow-cover extent during the last 10-15 yrs, especially in Eurasia; the rebound is not as pronounced in North America.

The purpose of the present paper is to assess whether or not snow in the North American and Eurasian high Arctic regions (70º north latitude) is disappearing earlier in the spring now than in prior decades. Here, more accurate and reliable satellite maps have been used to look at snow disappearance, not in just a few latitude bands as was the case in the 1992 study, but across much of the Arctic.

METHOLOGY

As in the Foster et al. (1992) paper, the date that snow first retreats north of the 70º parallel, is considered the date of snow disappearance in the present study. From the map in Figure 1, it can be seen that this parallel is the farthest north parallel lying in parts of both North America and Eurasia. It should be noted that the actual day the contiguous snowline retreats north of this artificial boundary is difficult to ascertain. Clouds are prevalent in the Arctic during the spring and may persist over a given area for days at a time. Nonetheless, these maps clearly show trends where change is greater than the period of mapping – typically seven days.

Satellite data on the date snow retreats north of the 70º parallel has been acquired from NOAA for all available 10º longitude bands in Eurasia and North America (Figure 1). These data are available from the late 1960s. In this study, 38 years of data -- from 1967-2004 are used. For the present study, strips were included in physiographic/climatic regions that incorporate tundra, boreal forest and alpine regimes. Note that the Alaska (North Slope) and Scandinavia (Kola Peninsula) sites are more marine in nature than are the Canada (Boothia Peninsula) and Siberian sites, which have a very high continentality.

NOAA SNOW CHARTS

The NOAA snow charts used here have been re-worked by the Rutgers University Global Snow Lab (RUCL) from visible satellite data, available since 1967. On these charts, snow is mapped on 1º x 1º grid blocks. Snow accumulation and ablation can be followed through the course of each snow season.

RESULTS

Figure 1 maps the 23 snow crossing zones for 70º north latitude. Looking at change in the length of the snow season between 1967 and 2004 (Figure 2), in north central Siberia, the season is decreasing in length (by less than a week), whereas just to the east of this region, the snow season is longer by several days. In North America (northern Alaska and Canada), the few available bands meeting our criteria show a decrease in the snow season length. Note that the cells north of Hudson Bay (19-23), on or near Baffin Island, are on occasion snow covered year-around and have been excluded from this analysis (see Table 1).

Though snow may fall in high latitude tundra locations throughout the year, an established snow cover will not usually first appear until between about mid September and mid October. Because this early season snow is typically non continuous and patchy, and because of the short daylight period in the autumn, reliably mapping the position of the snowline is a more difficult proposition in early fall than in late spring. At 70º north, there is little difference in the length of the snow season (Figure 3) and the date of spring snow disappearance.

To compare results from this study with earlier investigations (Foster et al., 1992), Figure 4 shows the dates of snow disappearance for four selected sites during the period 1976-1990. These four sites (10 degree longitude bands) were all located at 70º north latitude, and as mentioned earlier, the dates of snowmelt were also satellite-derived (using NOAA data). Note the trend toward earlier snowmelt. For the North Slope of Alaska, for instance, the trend indicates that the snow was melting nearly 3 weeks earlier in the late 1980s as compared to the mid 1970s. The snow melts earlier in the year on the North Slope and in Scandinavia (Kola Peninsula) sites and is more persistent on the Boothia Peninsula of Canada and over northern Siberian. On the North Slope, the snow melted in week 27 in 1976 and in week 20 in 1990. For the Scandinavian/Kola (SK) site, snow remained on the ground until week 28 in 1981 but disappeared in week 18 in 1989. For the sites having higher continentality, the date of disappearance was less variable; on the Boothia Peninsula, melting first occurred between weeks 25 and 29 and for northern Siberia, between weeks 23 and 29.

On Figure 5, the date when snow first retreated north of the 70º parallel is shown for the period from 1965-2004. Despite the fact that the snowline has retreated less noticeably in recent years than during the 1970s and 1980s, for the period from approximately 1970-2000, the trend lines nonetheless indicate (not shown here) that snow is melting about one week earlier in recent years than was the case 35 years ago.

Because reliable satellite observations are now available over fairly long time periods (30 years and more), and because systematic errors have been minimized over the years (Robinson et al., 2003), existing trends are likely to be statistically meaningful.

DISCUSSION

There are several scenarios that could account for the long-term (38-year) trend toward an earlier date of snow disappearance (for most bands) in the high Arctic. Global and/or regional warming could play a major role causing earlier snow disappearance. In addition, portions of the Arctic are known to be a sink for atmospheric pollutants, such as industrial particulates from sources in Eastern Europe, Russia and northern Kazakistan. Also, soot from wildfires in the boreal forests fall out across the Arctic (Foster et al., 1989; Hansen and Nazarenko, 2005). Even ash from major volcanic eruptions in the tropics and mid latitudes will settle out over the polar regions. Furthermore, in late spring, when the polar jet stream moves northward and low-level winds increase due to daily heating differences, dust from natural sources sullies the retreating snowpack, thus reducing the albedo, which helps to accelerate melting.

If in recent decades snowfall amounts were smaller than in the 1960s and 1970s, due to shifting storm tracks for instance, the snowpack would likely melt sooner. This by itself could account for the “warm up” of parts of the Arctic. Tundra snowpacks are typically thin compared to snow in wooded areas such as the taiga. A string of several seasons in near succession where the pack is not sufficiently augmented by winter and spring snowfall could lead to earlier melt over wide areas of the high Arctic. Even if this were the case, it nonetheless could have been initiated by a response to climate warming – a displacement in the normal position of the polar jet stream, for example. Factors such as the ones above, either by themselves or acting in concert, would assuredly act to speed up snowmelt.

An interesting finding in this study, however, is that the length of the snow season in the high Arctic has not noticeably shortened since the late 1960s (Figure 2). Seven of the nineteen latitude bands showed no change, or the snow season actually slightly increased in length. Though the overall snow season length has not substantially changed since the early portion of the study period, the snow is indeed disappearing earlier in the spring (Figure 3). Snow cover has actually been forming earlier in the autumn in recent years.

Of course, it could be that the Arctic is warming but that the date of snow disappearance is not particularly responsive to temperature fluctuations. It may also be that because of increasing Arctic temperatures and increasing evaporation rates (greater moisture availability), there has been an increase in snowfall as a result of the warmer environment. However, if this scenario is correct, then by using snow cover data alone, it would be difficult to discern any cooling episodes since both the dates of earlier snow disappearance and later disappearance could be attributed to Arctic warming – warmer temperatures melt snow more quickly or lead to increase snowfall. A new study by Bosilovich et al. (2005) indicates that the water cycle rate in atmospheric models is reduced as the air temperature warms. Over land, simulations showed that precipitation decreased at nearly all latitudes as the local recycling of water was reduced.

The Northern Hemisphere snow cover extent and the date of snow disappearance in high latitudes correspond fairly closely. Figure 6 shows a similar trend, as was observed using the week of snow disappearance, toward earlier snowmelt for the entire Northern Hemisphere during the period from 1973 – present. Referring to the trend line in Figure 6, the 12-month mean snow cover decreased from approximately 25 million km^2 in the early1970s to about 24 million km^2 in the early 2000s. When looking at the average June snow cover over this same period, the decline in snow extent is even more evident – from nearly 12 km^2 in the early 1970s to about 8 km^2 in the early 2000s. While the trends are similar between the date of snow disappearance and hemispheric mean monthly snow extent, the R^2 values are not particularly strong. For example, the coefficient of determination between the date of snow disappearance on the North Slope of Alaska and the Northern Hemisphere mean monthly snow cover is 0.221 – 22% of the variation in the date of disappearance is explained by the hemispheric monthly mean snow extent.

Since 1990, though, the hemispheric snow cover during June has changed very little (Figure 7), and there has actually been an increase of approximately 0.5 million km^2 for the 12-month mean Northern Hemisphere snow cover extent. Note that temperature records available north of the Arctic Circle show a cooling trend since the 1980s (Przybylak, 2000). A recent study by Frei and Gong (2005) showing minimal changes in snow cover in the Northern Hemisphere during the 1990s and 2000s also supports our findings.

The period of record for the Foster et al. (1992) paper coincided with the most noticeable change in the advancement of snowmelt during the past 40 years. This period was concomitant with increased Arctic warming. A number of strong signals indicate that warming of the polar areas has been underway in recent decades. For example, Abdalati et al. (2004) found that while some areas of the ice sheet on Greenland and the ice cap of the Canadian Archipelago are thickening, overall, the Greenland ice sheet as well as the Archipelago ice cap have been both thinning and shrinking. An increasing trend in both temperature and precipitation, and an increase in the fraction of the precipitation that falls as snow in the second half of the 20th century was noted.

However, in the Antarctic, portions of the East Antarctic Ice Sheet have been observed to be growing – gaining approximately 45 billion metric tons of mass per year between 1992 and 2003 according to a study by Davis et al. (2005). Furthermore, according to Markus and Cavalieri (in press), Antarctic sea ice extent has also been increasing in recent years. It is not unexpected that climate signals may appear to contradict one another, temporally and spatially. Different features may respond to warming, or cooling, in different ways.

Similarly, during the past 15 years, a relative stability in the date of snow cover disappearance in the high Arctic (or even a slightly later date at some locations), should not be construed as a sign that the earlier snowmelt observed in the 1970s and 1980s was an aberration. Still, it demonstrates that the evidence for global warming is not completely incontrovertible, even in the Arctic.

CONCLUSIONS

In this study, the date the snowline retreats during the spring (when it first moves north of the 70 degree parallel), for many Arctic locations, has occurred approximately a week earlier in recent years compared to the late 1960s. Thus, the tendency toward earlier snowmelt observed previously has neither been a local phenomenon nor a short-term fluctuation. Nonetheless, it appears that since 1990, the date the snowline first retreats north during the spring has remained nearly unchanged --in the last 15 years, the date of snow disappearance has not been occurring noticeably earlier, but snow cover has actually been forming earlier in the autumn.

REFERENCES

Abdalati W., W. Krabill, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, J. Yungel, R. Koerner: Elevation changes of ice caps in the Canadian Arctic Archipelago, J. Geophys. Res., 109, F04007, 2004.

Bartlett, M. G., D. S. Chapman and R. N. Harris: Snow effects on North American ground temperatures, 1950-2002, J. Geophys. Res., 110, F03008, 2005..

Bosilovich, M., S. Schubert, and G. Walker: Global Changes of the Water Cycle Intensity. J. Climate, 18, 1591-1608.

Budyko, M. I.: Polar ice and climate, *Proceedings of the Symposium on the Arctic Heat Budget and Atmospheric Circulation*, RM 5233-NSF, edited by J. O. Fletcher, pp 3-21, Rand Corporation, Santa Monica, CA, 1966.

Comiso, J. C., J. Yang, S. Honjo, and R. Krishfield: Detection of change in the Arctic using satellite and in-situ data. J. Geophys. Res., Vol. 108, No. C12, 24pp, 2002.

Comiso, J. C.: Warming Trends in the Arctic from Clear Sky Satellite Observations. J. Climate., Vol. 16, No. 21, 3498-3510, 2003.

Comiso, J. C., Parkinson, C.L.: Satellite-Observed Changes in the Arctic. Physics Today, 38-43, August, 2004.

Davis, C., Y. Li, J. McConnell, M. Frey, E. Hanna: Snowfall-Driven Growth in East Antarctic Ice Sheet Mitigates Recent Sea-Level Rise. Science Express, 2005, 1898-1901.

Foster, J. L.:The significance of the date of snow disappearance on the Arctic tundra as a possible indicator of climatic change, Arct. Alp. Res., 21(1), 60–70, 1989.

Foster, J. L., J. W. Winchester, and E. G. Dutton: The date of snow disappearance on the Arctic tundra as determined from satellite, meteorological station and radiometric in situ observations, IEEE Trans. Geosci. Remote Sens., 30(4), 793–798, 1992.

Frei, A. and G. Gong: Decadal to century scale trends in North American snow extent in coupled atmosphere-ocean general circulation models, Geophysical Research Letters, 32, L18502, doi:10.1029/2005GL023394, 2005.

Hansen, James and Larissa Nazarenko: Soot climate forcing via snow and ice albedos, PNAS, Vol, 101, No. 2, 423-428, 2004.

Manabe, S., M. J. Spelman, and R. J. Stoufer: Transient responses of a coupled ocean–atmosphere model to gradual changes of atmospheric CO_2. Part II: Seasonal response. J. Climate. Vol., 5, 105–126, 1992.

Markus, T., and D.J. Cavalieri, Interannual and regional variability of Southern Ocean snow on sea ice and its correspondence with sea ice cover and atmospheric circulation patterns, Ann. Glaciol., 2005 (submitted).

Przybylak, R.:Temporal and spatial variations of surface air temperature over the period of instrumental observations in the Arctic, International J. Clim., Vol. 20, 587-614, 2000.

Robinson, D. and K. Dewey: Recent secular variations in the extent of Northern Hemisphere snow cover, Geophysical Res.Letters, Vol. 17, No. 10, 1557-1560, 1990.

Robinson, David, Allan Frei, and Mark Serreze. 1995. Recent Variations and Regional Relationships in Northern Hemisphere Snow Cover, Annals of Glaciology (21), 71-76.

Robinson, David A. and Allan Frei, 2000**.** Seasonal Variability of Northern Hemisphere Snow Extent using Visible Satellite Data, Professional Geographer, 52 (2), 307-314.

Walsh, J. E. and W. L. Chapman: Short-term climate variability of the Arctic, J. Climate, Vol. 3, No. 2, 237-250, 1990.

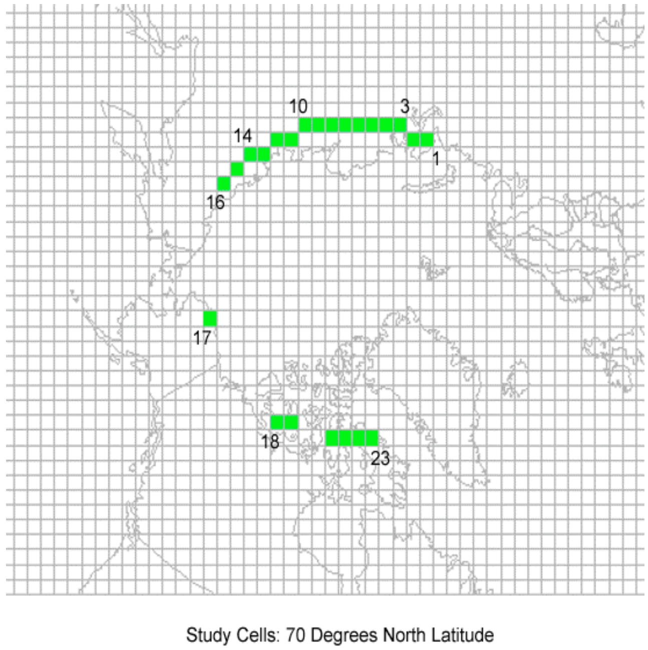

Figure 1
Figure 1 shows the 23 snow crossing zones for 70 degrees north latitude

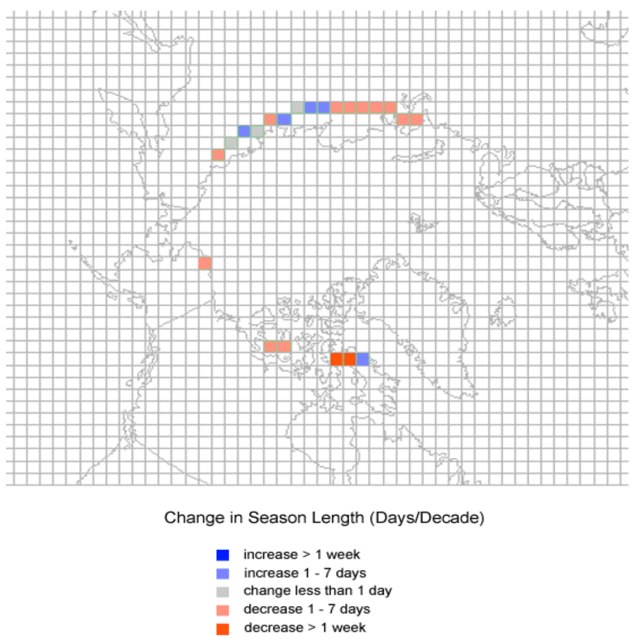

Figure 2
Figure 2 -- Shows change in the length of the snow season (70 degrees latitude at 90-100 degrees east longitude) between 1967 and 2004

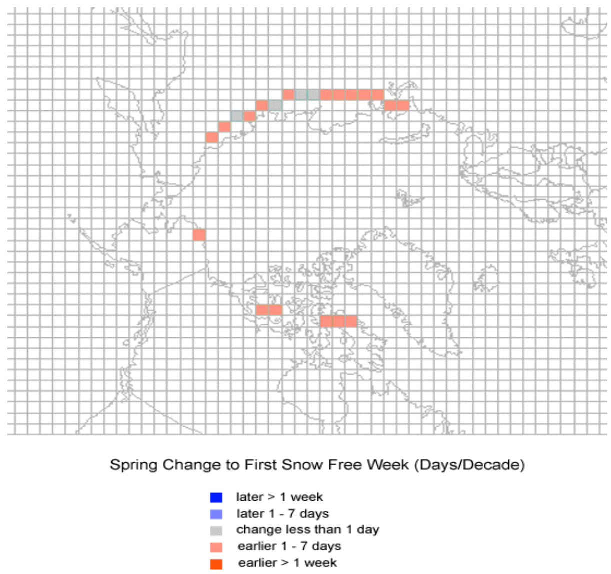

Figure 3

Figure 3 -- Figure showing first snow free week during spring at 70 degrees north

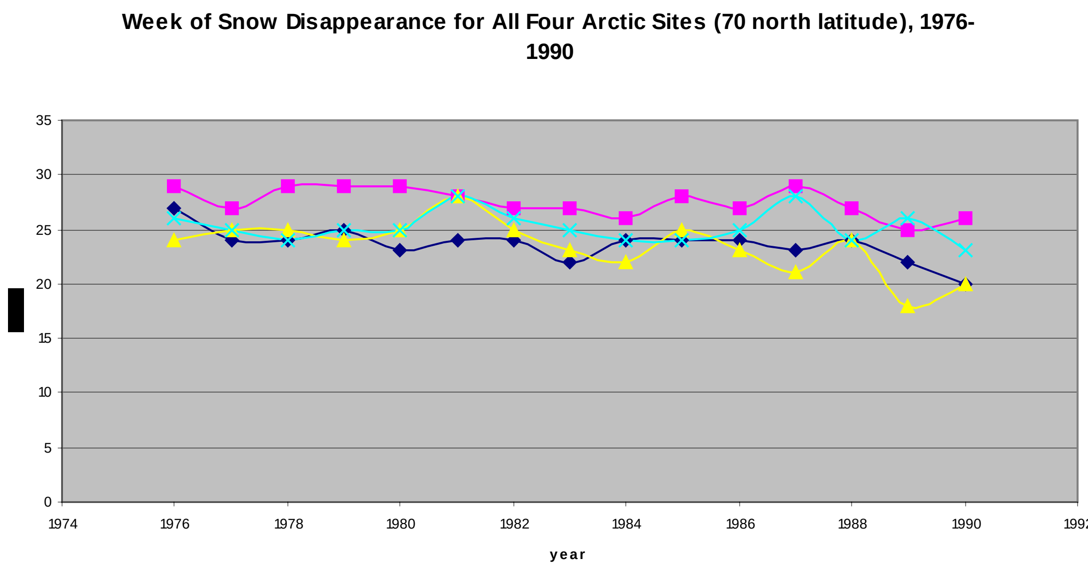

Figure 4

Figures 4 -- Chart showing date of snow disappearance for the period 1976-1990 at four sites (70 degrees north latitude) for the 1992 study - Yellow (Scandinavia/Kola Peninsula), Aqua (Siberia), Magenta (Boothia), Blue (North Slope)

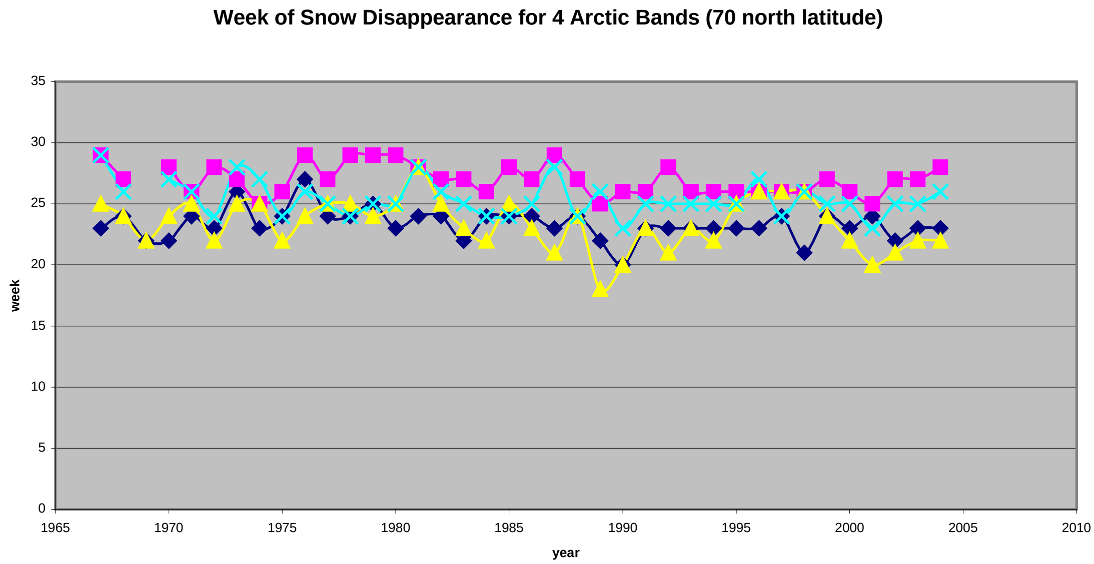

Figure 5

Figure 5 -- Chart showing date of snow disappearance for the period 1965-2004 for the same four sites - Yellow (Scandinavia/Kola Peninsula), Aqua (Siberia), Magenta (Boothia), Blue (North Slope)

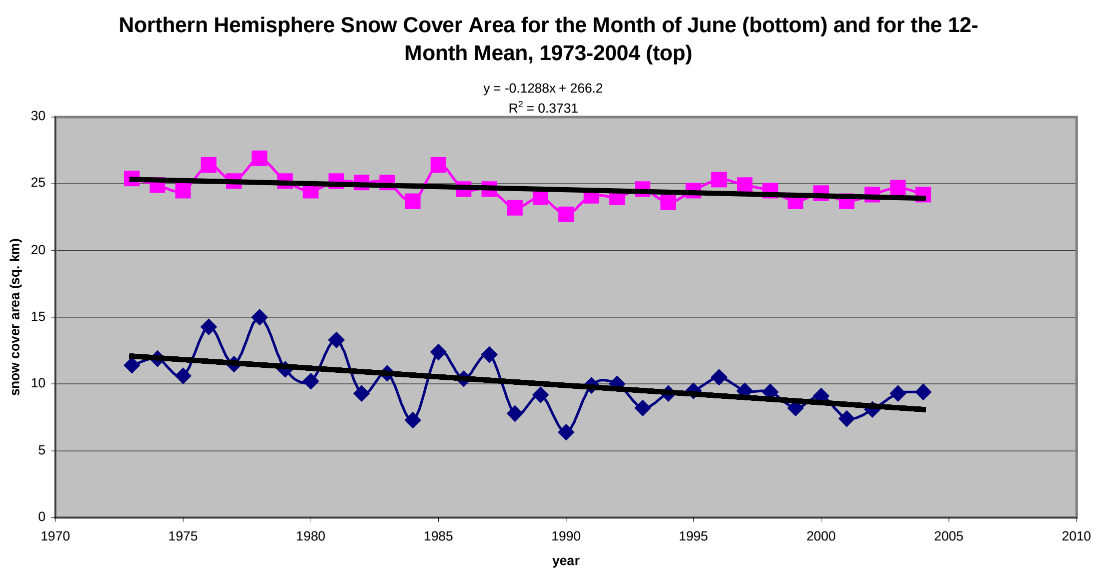

Figure 6

Figure 6 -- North America snow cover for the month of June versus the 12-month mean snow cover – 1973-2004

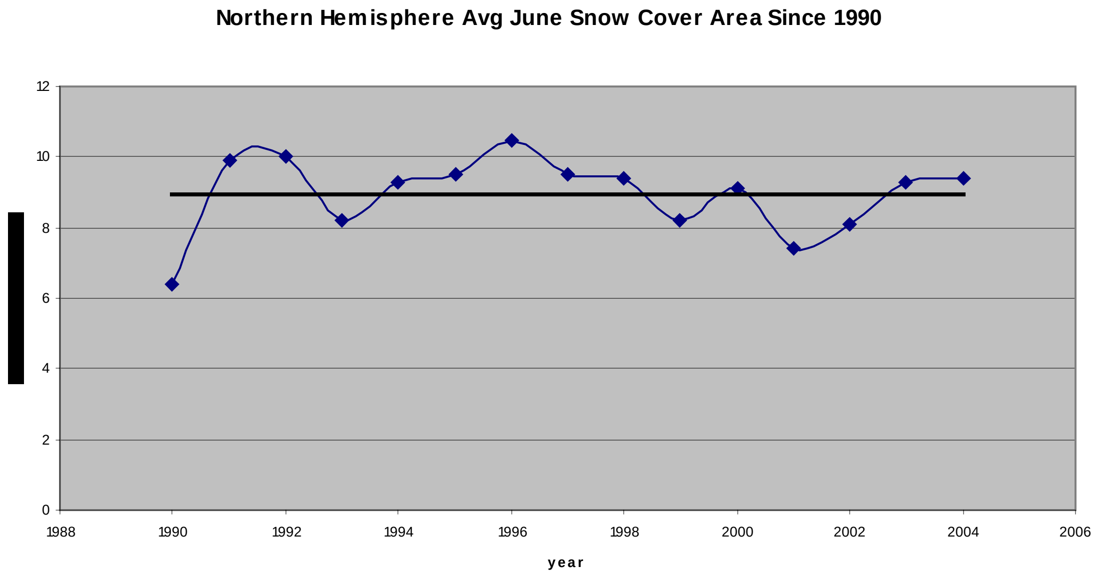

Figure 7
Figure 7 -- Northern Hemispheric average June snow cover since 1990

Cell	70N Change in Season Length (1967-2004)								
	Weeks	Days	Days/Decade	Location					
1	-2.21	-15.47	-4.07	50, 54					
2	-2.23	-15.61	-4.11	49, 54					
3	-2.66	-18.62	-4.90	48, 55					
4	-1.42	-9.94	-2.62	47, 55					
5	-2.08	-14.56	-3.83	46, 55					
6	-2.09	-14.63	-3.85	45, 55					
7	-1.27	-8.89	-2.34	44, 55					
8	1.06	7.42	1.95	43, 55					
9	0.76	5.32	1.40	42, 55					
10	-0.46	-3.22	-0.85	41, 55					
11	0.94	6.58	1.73	40, 54					
12	-0.93	-6.51	-1.71	39, 54					
13	-0.28	-1.96	-0.52	38, 53					
14	1.69	11.83	3.11	37, 53					
15	-0.42	-2.94	-0.77	36, 52					
16	-2.20	-15.40	-4.05	35, 51					
17	-0.79	-5.53	-1.46	34, 42					
18	-1.73	-12.11	-3.19	39, 35					
19	-2.52	-17.64	-4.64	40, 35					
20				43, 34	changes in data 1980, no data after 1999				
21	-5.18	-36.26	-9.54	44, 34					
22	-3.99	-27.93	-7.35	45, 34	snow covered year round for 4/38 years (11%)				
23	2.44	17.08	4.49	46, 34	snow covered year round for 11/38 years (29%)				
mean	-1.16	-8.14	-2.14						

Table 1
Table 1 – Change in snow season length from 1967-2004